# WIDEBAND AMPLIFIERS

When analyzing amplifiers mathematically, it is convenient to assume that the gain calculations are not affected by the reactive elements that might be present in the circuit. However, in reality, capacitances and inductances play a major role in determining how the amplifier performs over a range of frequencies. The effect of inductances can be minimized but it is impossible to ignore the presence of capacitances. This effect is more pronounced particularly while analyzing multistage amplifiers. Coupling capacitors and bypass capacitors can reduce the gain of an amplifier at lower or higher frequencies, because the capacitive reactance is inversely proportional to the frequency. In other words, as the frequency increases, the capacitive reactance decreases because

$$X_c = \frac{1}{j(2\pi fC)}$$

Therefore, if there is a grounded bypass capacitor, signal currents may be inadvertently diverted to ground instead of being transmitted to the output. This is because bypass capacitors offer low reactances to signal currents at higher frequencies. However, the bypass capacitors offer high reactances to signals at lower frequencies, and therefore diversion of such currents to ground does not pose a major problem.

Figure 1 is a representation of a frequency plot of an amplifier. Here, the output voltage or power gain is plotted against a range of frequencies (for a given constant input voltage). The frequency axis is normally plotted on a logarithmic scale. The unit for the $y$ axis is decibels (dB); the number of decibels of gain is given by

$$20\log_{10}\frac{V_O}{V_I}$$

or

$$10\log_{10}\frac{P_O}{P_I}$$

Consider the case when $P_O = \frac{1}{2}P_I$. Then the gain in decibels is

$$10\log_{10}\tfrac{1}{2} = -3.0103$$

Therefore, for audio engineers the point of interest lies where the gain falls by 3 dB. The frequencies at which this occurs are called *half-power frequencies.* Let the flat portion of the amplifier characteristic be assigned a voltage level of $V_{flat}$. Then the frequencies at which voltage levels have dropped to $0.707V_{flat}$ are denoted by $f_L$ and $f_H$. The range of frequencies that lies between $f_L$ and $f_H$ is known as the bandwidth. In other words, the bandwidth can be defined as the frequency range over which the amplifier gain remains within 29.3% of its maximum value (3 dB level, or $1 - 0.707 = 0.293$).

The bandwidth of an amplifier depends upon the applications and signal type involved. Bandwidth values for some selected electronic signals are given in Table 1.

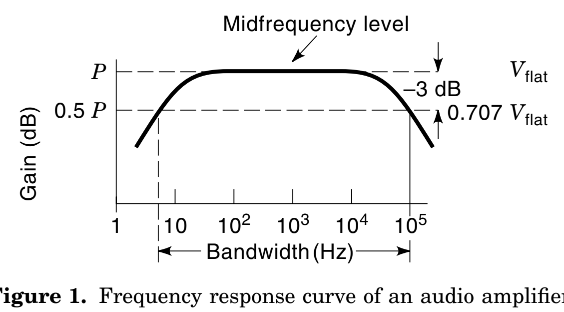


**Figure 1.** Frequency response curve of an audio amplifier.

**Table 1. Bandwidth Values for Selected Electronic Signals**

| Signal Type | Frequency Range |
|---|---|
| Electrocardiograms | 0.05 to 100 Hz |
| Audio signals (human ear) | 20 Hz to 15,000 Hz |
| AM radio waves | 550 kHz to 1600 kHz |
| FM radio waves | 88 MHz to 100 MHz |
| Microwave and satellite signals | 1 GHz to 50 GHz |

## PRINCIPLES OF FEEDBACK

For a simple amplifier the voltage gain is defined as the ratio of output voltage to input voltage. This is written as $A_V = V_O/V_I$ as shown in Fig. 2(a). Addition of a feedback of magnitude $\beta$, as shown in Fig. 2(b), will result in a modified value for the voltage gain given by the equation: $A'_V = A_V/(1 - \beta A_V)$. The term $\beta A_V$, called the *feedback factor,* can be either positive or negative. A study of the variation of $A'_V$ with positive as well as negative values of $\beta$ is shown in Fig. 2(c,d). It is observed that the value of $A'_V$ becomes infinite with only 10% of positive feedback. However, this should not be viewed as advantageous, because positive feedback greatly increases distortion in the output. Mathematically it is true that the gain approaches infinity; however, in reality, the circuit begins to oscillate. Positive feedback does not find many applications.

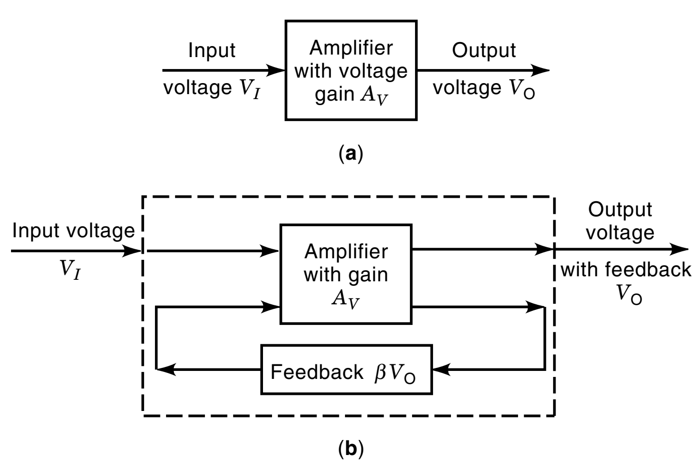


**Figure 2.** (a) Block diagram of an amplifier with $A_V = V_O/V_I$. (b) Block diagram of an amplifier with feedback. The dashed line encloses the entire amplifier including the feedback; its gain is $A'_V = V'_O/V_I$.

However, in 1932, Harry Nyquist of Bell Telephone Laboratories extended this theory at length and published his famous paper on *regenerative theory*. His principles laid the foundation for the development of feedback oscillators. Therefore, positive feedback is also called *regenerative* feedback. While designing frequency-selective feedback circuits for audio amplifiers, one may use positive feedback either as a bass or as a treble boost.

## NEGATIVE FEEDBACK

As shown in Figure 2(d), with 10% negative feedback, the gain $A'_V$ drops to half of $A_V$. In other words, negative feedback reduces the overall gain of an amplifier. Therefore it is called *degenerative* feedback. Here, a portion of the amplifier output is fed back to the input in such way that it opposes the input. Consider the case when $A'_V = A_V/100$. Since the gain in decibels is defined as 20 $\log_{10}(V_O/V_I)$, the reduction of the gain by a factor of 100 means a loss of 20 $\log_{10} \frac{1}{100} = -40$ dB. Thus, expressed in decibels,

$$A'_V = A_V - 40\,\mathrm{dB}$$

Now we can revisit Fig. 1 and study the frequency response with and without negative feedback. This is shown in Fig. 3. We can easily see that the bandwidth of the amplifier has been increased with negative feedback. This is the greatest advantage of negative-feedback amplifiers. In addition, negative feedback results in stabilized amplifier gain, extended bandwidth, and reduced noise and distortion. In other words, it is possible to achieve predictable voltage gains with negative feedback amplifiers. Besides, the resulting amplifiers are very stable.

It is possible to prove that series voltage feedback increases the input impedance of the circuit. The input impedance can be reduced by incorporating a parallel current feedback.

We can rewrite the previously considered equation incorporating the negative sign as

$$A'_V = \frac{A_V}{1 + \beta A_V}$$

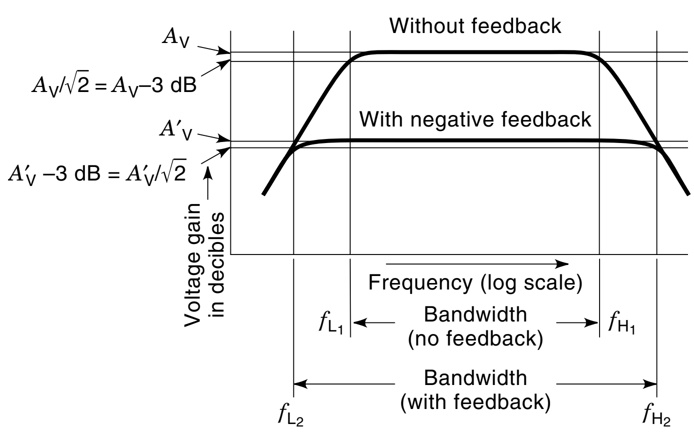


**Figure 3.** Bandwidth increases for an amplifier with negative feedback.

For very large values of $A_V$ the above equation becomes

$$A'_V \approx 1/\beta$$

Consider a case when $A_{V2} = (1 + 0.707)A'_V = 1.707/\beta$. Recalculate the new closed-loop gain with negative feedback:

$$\begin{aligned} A'_{V2} &= \frac{A_{V2}}{1 + \beta A_{V2}} \\ &= \frac{1.707/\beta}{1 + (1.707\beta/\beta)} \\ &= 0.707/\beta \\ &= 0.707 A'_V \end{aligned}$$

Observe that the above equation is independent of $A_V$, which is the gain without feedback. (also sometimes called the *open-loop gain*). In other words, even though the open-loop gain falls by a factor 1.707, the closed-loop gain falls only by 3 dB.

Similarly, we can prove

$$\text{Percentage distortion with negative feedback} = \frac{\text{Percentage distortion without negative feedback}}{1 + \beta A_V}$$

Negative feedback also helps in reducing the circuit noise. Thus, the signal-to-noise ratio is greatly improved:

$$(S/N)_{\text{feedback}} = (1 + \beta A_V)(S/N)_{\text{no feedback}}$$

## MILLER EFFECT

While designing amplifiers, engineers may assume that the internal capacitances in the transistor are very small compared to the external capacitances. But in reality, capacitances do exist between the base and emitter ($C_{BE}$) as well as between base and collector ($C_{BC}$). This is shown in Fig. 4. It can be mathematically shown that the total input capacitance

$$C_I = C_{BE} + (1 + A_V)(C_{BC})$$

In other words, the total input capacitance is the parallel combination of $C_{BE}$ and $(1 + A_V)C_{BC}$. The base–collector capacitance has been amplified by a factor of $1 + A_V$. This is called the *Miller effect*.

As mentioned earlier, as the frequency increases, the value of the total input impedance decreases and thereby the fre-

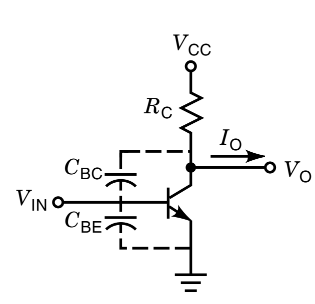


**Figure 4.** Miller effect with the transistor internal capacitances $C_{BC}$ and $C_{BE}$.

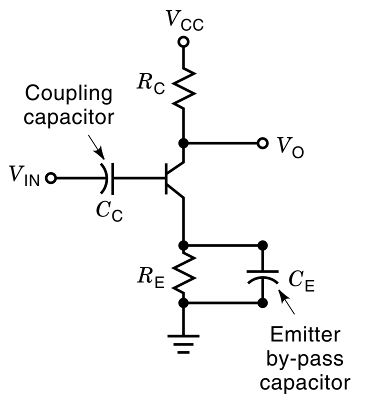


**Figure 5.** The impedances of $C_C$ and $C_E$ are large at low frequencies, and portions of signal voltages may be lost.

quency response characteristics are affected. The Miller effect is especially pronounced with common-emitter amplifiers, because they introduce a 180° phase shift between the input and the output. For example, the values of $C_{BE}$ and $C_{BC}$ may be small, say 5 pF and 4 pF. But when the transistor is used in an amplifier with a gain of 99, the total input capacitance will be large enough to affect the frequency output characteristics of the amplifier. This is because

$$\begin{aligned} C_I &= C_{BE} + (1 + A_V)(C_{BC}) \\ &= 5 + (1 + 99)(4) = 405\,\text{pF} \end{aligned}$$

It is recalled that at low frequencies the coupling capacitor and the emitter bypass capacitors offer high impedances and therefore portions of signal voltage may be lost, as shown in Fig. 5.

The Miller effect is thus an extremely important concept in discussing feedback. Equations for calculating the *Miller input impedance* and *Miller output impedance* can be developed, and are given below:

$$Z_{I,\text{Miller}} = \frac{Z_{\text{feedback}}}{1 - A'_V}$$

$$Z_{O,\text{Miller}} = \frac{A'_V Z_{\text{feedback}}}{A'_V - 1}$$

where $A'_V$ is the voltage gain *with* feedback $Z_{\text{feedback}}$

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